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Estimation of the available rooftop area for installing the rooftop solar photovoltaic (PV) system by analyzing the building shadow using Hillshade analysis

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Abstract

For continuous promotion of the solar PV system in buildings, it is crucial to analyze the rooftop solar PV potential. However, the rooftop solar PV potential in urban areas highly varies depending on the available rooftop area due to the building shadow. In order to estimate the available rooftop area accurately by considering the building shadow, this study proposed an estimation method of the available rooftop area for installing the rooftop solar PV system by analyzing the building shadow using Hillshade Analysis. A case study of Gangnam district in Seoul, South Korea was shown by applying the proposed estimation method.

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Keywords: Rooftop solar photovoltaic (PV) system; Hillshade analysis; Building shadow; Available rooftop area

1. Introduction

With climate changes and air pollution increasingly being recognized as global issues, many countries are exerting various efforts to reduce greenhouse gas emissions and cope with global warming [1]. Part of such efforts is the growing interest in distributing NRE and NZEB. In particular, solar PV systems,

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comprising of pure energy with unlimited potential, have been recognized as the most optimal NRE system to be applied to buildings in order to achieve NZEB.

In order to continue to promote the deployment of the solar PV system in buildings and to develop future plans and policies for installation of the solar PV system, it is crucial to understand and quantify the rooftop solar PV potential. When quantifying the rooftop solar PV potential, it is extremely important to accurately calculate the available rooftop area where the solar PV system can be installed. In urban areas where high-rise buildings are crowded, the available rooftop area for installing the solar PV system is largely dependent on the shadows from surrounding buildings. Therefore, shade areas due to surrounding buildings should be excluded when calculating the available rooftop area in urban areas. However, most of the previous studies [2-4] analyzed the rooftop solar PV potential by approximating the shade area with a certain percentage of the total rooftop area.

This study aims to develop an estimation method of the available rooftop area for installing the rooftop solar PV system by analyzing the building shadow. To analyze the building shadow on the rooftop based on the altitude and azimuth of the sun, this study used Hillshade Analysis. Toward this end, the study was conducted as follows: (i) data collection and conversion; (ii) building shadow analysis using Hillshade Analysis; and (iii) estimation of the available rooftop area. The proposed estimation method was applied to the following region and day in order to show the step-by-step procedure: (i) Gangnam district in Seoul, South Korea, where there are many high-rise buildings; and (ii) spring equinox, which is one of the representative days of a year based on the location of the sun.

Nomenclature

NRE	New Renewable Energy
NZEB	Nearly Zero Energy Building
PV	Photovoltaic
NGII	National Geographic Information Institute
KASI	Korea Astronomy & Space science Institute

2. Material and Methods

2.1. Step 1: Data collection and conversion

In step 1, this study collected the building elevation data in Gangnam district and converted them into manageable form for the Hillshade analysis. First, this study collected the building data in Gangnam district from NGII under the Ministry of Land, Infrastructure, and Transport. NGII offers national geographic information and supports map production and distribution. The building data in Gangnam district were provided in shapefile (.shp) format as polygon data (vector data) which contained the building elevation data as an attribute. Second, this study converted the building elevation data into manageable form for the Hillshade analysis. The vector data needs to be converted into raster data in order to conduct Hillshade analysis. This study used the Polygon to Raster tool from ArcGIS 10 to convert the vector data into raster data.

2.2. Step 2: Building shadow analysis

In step 2, this study conducted the building shadow analysis using the *Hillshade* tool from *ArcGIS 10* in order to calculate the shade area based on the altitude and azimuth of the sun. In order to conduct the building shadow analysis using the *Hillshade* tool requires the following as input data: (i) the building elevation data as raster data; and (ii) the altitude and azimuth of the sun at the time of the analysis. To calculate altitude and azimuth of the sun at spring equinox, this study used *Sun Altitude and Azimuth Calculation* tool from KASI [5]. This study calculated the altitude and azimuth of the sun in Seoul on March 21, 2014, and used the data from 7AM to 6 PM (when sun is above the horizon) as the input data for the Hillshade tool. The Hillshade analysis was conducted every hour from 7AM to 6 PM. The output raster are in gray scale between 0 and 255. The lower the gray scale (0 = black), the stronger the shadow is. The higher the gray scale (255 = white), the weaker the shadow is.

2.3. Step 3: Estimation of the available rooftop area

In step 3, this study estimated the available rooftop area for installing the solar PV system by excluding shade areas based on the Hillshade analysis and areas where the solar PV system cannot be installed. First, this study converted the Hillshade analysis result displayed in gray scale from 0 to 255 into a binary image in order to categorize the output raster based on the existence of building shadows. To convert the analysis result into a binary image, the study set the value most frequently shown in the gray scale as a threshold. Second, this study converted the output raster into polygon using the Raster to Polygon tool from *ArcGIS 10* in order to additionally exclude the area where the solar PV system cannot be installed. A 2kW solar PV system, which is the average minimum installed capacity for the residential solar PV system requires at least $20m^2$ as installed area. Thus, if the area of each polygon (which was converted from output raster) exceeds $20m^2$, these polygons need to be excluded from the available rooftop area. In this way, small or irregular areas on the rooftop where it is difficult to install a PV system can be excluded.

3. Theory/Calculation

To quantify the building shadow and calculate the available rooftop area for installing the solar PV system, the study used Hillshade analysis. The hillshade can be calculated by setting the location of a hypothetical light source and calculating the shade value of each cell in the raster. To calculate the building shadow based on the building elevation using such algorithm, the study used the *Hillshade* tool in *ArcGIS 10*.

3.1. Hillshade algorithm

The altitude and azimuth of the light source (the sun) is necessary to calculate the shade value of each cell in the raster. The altitude and azimuth of the sun are used along with the aspect and slope for determining the final hillshade value of each cell in the raster. The algorithm used in calculating the hillshade value is shown in Eqs. (1) to (5) [6].

$$Hillshade = 255 \times \left\{ \begin{array}{l} \left[\cos(Zenith_{rad}) \times \cos(Slope_{rad})\right] \\ + \left[\begin{array}{l} \sin(Zenith_{rad}) \times \sin(Slope_{rad}) \\ \times \cos(Azimuth_{rad}) \times \cos(Aspect_{rad}) \end{array} \right] \end{array} \right\} \quad (1)$$

$$Zenith_{\deg} = 90 - Altitude \tag{2}$$

$$Zenith_{rad} = \frac{Zenith_{\deg} \times \pi}{180} \tag{3}$$

$$Azimuth_{math} = 360 - Azimuth_{\deg} + 90 \tag{4}$$

$$Azimuth_{rad} = \frac{Azimuth_{\deg} \times \pi}{180} \tag{5}$$

4. Results and Discussion

The available rooftop area for installing the solar PV system in Gangnam district is estimated by excluding shade areas and areas where the solar PV system cannot be installed. The polygons in Figure 1 refer to buildings in Gangnam district. The area in black and gray in Fig. 1 refers to the following: (i) black: shade areas and areas where the solar PV system cannot be installed; and (ii) gray: available rooftop areas for installing the solar PV system.

Fig. 1. The available rooftop area in Gangnam district on spring equinox at (a) 1PM (left) and (b) 3PM (right)

Estimated available rooftop areas from 7AM to 6 PM (hourly) in Gangnam district on spring equinox is shown in Table 1. The hour when the available rooftop area is smallest is at 7AM, with the ratio of the available rooftop area to the total rooftop area at 35.90%. The hour when the available rooftop area is largest is at 10AM, when the ratio of the available rooftop area to the total rooftop area is 73.20%. On average, the available rooftop area and its ratio to the total rooftop area in Gangnam district on spring equinox was 4,903,079m^2 and 65.22%, respectively.

Table 1. The available rooftop area in Gangnam district on spring equinox

Time	Available rooftop area (m^2)	Ratio to total rooftop area
7AM	2,700,441	35.92%
8AM	4,688,041	62.36%
9AM	5,369,568	71.42%
10AM	5,502,711	73.20%
11AM	5,437,957	72.33%
12PM	5,265,380	70.04%
1PM	5,247,008	69.79%
2PM	5,339,364	71.02%
3PM	5,445,072	72.43%
4PM	5,267,465	70.07%
5PM	4,931,185	65.59%
6PM	3,642,749	48.45%
Average	4,903,079	65.22%

5. Conclusions

The study developed a method to estimate the available rooftop area for installing the solar PV system using Hillshade analysis. The proposed method was applied to Gangnam district in Seoul on the spring equinox. Toward this end, the study was conducted in three steps: (i) data collection and conversion; (ii) building shadow analysis using Hillshade analysis; and (iii) estimation of the available rooftop area. The available rooftop area that the solar PV system can be installed came out to be 4,903,079m^2 on average on the spring equinox in Gangnam district. The proposed method is superior to methods from previous studies in terms of usefulness as follows: it is a fast and easy method to (i) analyze building shadow and (ii) calculate shade areas for all buildings throughout a certain region at the same time.

Further research will be carried out to solve the following limitations: (i) lack of feasibility of the optimal threshold value of gray scale which determines the existence of building shadows; (ii) insufficient process for treating irregularly shaped polygons; and (iii) absence of method which can unify the hourly output raster to daily result.

The available rooftop area estimated from the proposed method can be used in several ways: (i) quantify the rooftop solar PV potential in urban areas; (ii) evaluate buildings according to the rooftop solar PV potential; (iii) select the optimal building for installing the solar PV system; and (iv) establish and improve the nation’s long-term solar policies.

6. Copyright

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Biography

Minhyun Lee is a graduate student in Department of Architectural Engineering, as well as a researcher in SUStainable Construction Management (SUSCOM) Laboratory at Yonsei University in South Korea. She conducts various studies on economic, environmental, and social impacts and management skills during the life cycle of the construction projects.